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APPLICATION OF RADIATION DATA TO MAXIMUM TEMPERATURE FORECASTING[1]

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ABSTRACT

A method is developed for evaluating the local heating and cooling by radiation and related processes, for predicting the daily maximum temperature at Nashville, Tenn.

1. INTRODUCTION

There is no fact more common in man's life than that each day our environment is warmed by the sun. Yet for the weather forecaster to consider the sunshine in a quantitative way in predicting the daily maximum temperature is far from universal. This paper reports on a method for assessing the net heating by insolation in forecasting the daily maximum temperature at Nashville, Tenn. The method is an expansion of that developed by Neiburger [12] for predicting maximum temperatures at Chicago. Williams [19] recently devised a similar procedure for Las Vegas, Nev., and Phoenix, Ariz. Jefferson [6] has published a note on this type of approach to temperature forecasting in England. Nashville was chosen for the present study because it is both a radiosonde and a pyrheliometric station and because there are neither mountains nor large bodies of water in the immediate environment.

One byproduct of the investigation is the diurnal variation of the clear-weather heat balance. From these data, shown in graphical form for alternate months of the year, the net heating or cooling of the air between any two times of day can be estimated. A second byproduct is the total net daily heating. It was found that insolation absorbed at the ground appreciably exceeds all day and night heat losses under cloudless conditions at Nashville throughout the year, except possibly within a week or two of the winter solstice. This partly accounts for the warming of southward-moving airmasses at the latitude of Nashville.

2. THE LOCAL HEAT BALANCE

The energy-balance equation at the surface of the ground as employed by Neiburger is:

$$H_0=I_0-RI_0-B_0-S-LE \qquad (1)$$

where H_0 is the heat conducted from the ground to the air, I_0 the solar radiation reaching the ground, R the albedo or reflectivity of the ground surface, B_0 the net long-wave radiation, positive upward, S the heat entering the ground and raising its temperature, L the latent heat of evaporation, and E the amount of water evaporated or transpired. The equation is also valid for the cooling of air at night.

This study seeks to account for the diurnal change in heat content of the layer of air extending upward from the

[1] Paper presented at the 137th National Meeting of the American Meteorological Society, Kansas City, Mo., June 8-10, 1955.

ground a few thousand feet in which the principal daily fluctuation of temperature occurs. In cloudless weather the flux of heat, H_a, into a vertical column of unit cross section through this layer is:

$$H_a = H_0 + m(I_a + RI_0) - (B_a - B_0) + A \qquad (2)$$

where m is the fraction of short-wave insolation absorbed by clear air of the column, including water vapor, I_a the insolation at the top of the layer, B_a the net long-wave radiation at the top of the layer, positive upward, and A the advection of heat into the column by horizontal and vertical air movements. The sum of the fluxes on the right in equation (2), excepting A, will be symbolized by H:

$$H_a = H + A \qquad (3)$$

The primary objective of this study was to estimate climatological values of H to enable the forecaster to estimate H_a by inserting his own estimate of A into equation (3), or by neglecting A if it is small.

The absorption of insolation by the air, $m(I_a + RI_0)$, is usually the smallest of the energy fluxes in equation (2) and is not as large as probable errors in other fluxes. This term is neglected in the remainder of the present study. With this approximation and combining equations:

$$H = I_0 - RI_0 - B_a - S - LE \qquad (4)$$

Estimates of the climatological normal values of H in clear weather were obtained by substituting in equation (4) estimates of the five quantities on the right-hand side. This was done on an hourly basis for February, April, June, August, October, and December.

Insolation, I_0.—Essentially cloudless days at Nashville from January 1945 through September 1946 were identified as those on which both 100 percent of possible sunshine from the sunshine recorder ("triple register") and either "zero" or "less than one-tenth" daily mean cloudiness by eye observation, was reported in the Monthly Meteorological Summary [18]. Hourly totals of direct and diffuse solar radiation on those days, as recorded by the Nashville pyrheliometer, were plotted against date, and annual curves of insolation for each hour were drawn to the data. Hourly values of insolation were read from the curves at the 15th day of alternate months and are listed in table 1.

TABLE 1.—*Cloudless-sky hourly insolation on a horizontal surface, Nashville, Tenn. Based on data from January 1945 through September 1946.*

Hour ending local mean solar time	Insolation on the 15th day of the month (langleys/hr)					
	February	April	June	August	October	December
a. m.						
6	0	1	5	2	0	0
7	0	9	20	15	0	0
8	7	30	40	32	10	1
9	21	50	56	49	25	15
10	37	63	70	65	40	29
11	52	74	80	76	54	36
12	58	80	87	81	61	42
p. m.						
1	61	81	86	83	63	43
2	56	76	80	77	57	39
3	41	63	71	66	44	28
4	27	47	57	51	29	15
5	8	30	39	33	11	3
6	1	9	20	15	1	0
7	0	1	5	2	0	0
Total	369	614	716	647	395	251

Albedo, R.—Shaw [15], Fritz [3], and List [11] have tabulated values of the albedo (percentage of sunshine reflected) of various natural surfaces. Some of the values most applicable to the environment of Nashville are those obtained by Kalitin [8] over a field of grass in Poland in spring. His values when the field was dry ranged from 0.18 to 0.23. Neiburger used an albedo of 0.21, the mean of Kalitin's measurements. In the present study an albedo of 0.20 was considered representative for Nashville, that is, 20 percent of each value in table 1 was considered as heat lost to the earth by reflection. Williams used a slightly lower value of 0.17 in consideration of the terrain around his two stations.

Long-Wave Radiation, B_a—The upward long-wave radiation which dissipates heat from the ground is absorbed by the water vapor of the atmosphere. This energy is reradiated both upward and downward. The net upward radiation through any level may be estimated by use of various radiation charts, if the temperature and water vapor distribution in the atmosphere and temperature of the ground are known. The radiation chart of Elsasser [2] was employed to compute the net upward radiation through the 1.5-km. (mean sea level) surface from selected mean monthly raob soundings at Nashville. In an attempt

TABLE 2.—*Air and ground temperatures (° F.) at Nashville, Tenn. and computed net upward fluxes of long-wave radiation through the 1.5-km. surface during selected months*

Month	Air temperature (observed)				Ground temperature (estimated)	Long-wave flux through 1.5-km. surface (langleys/hr)			
	Departure from normal	Mean for 2115 CST	Mean of daily min. temp.	Mean of daily max. temp.	Mean max. (at solar noon)	2115 CST	Sunrise	1600 CST	Mean local noon (1148 CST)
Feb. 1943	1.6	42	32	54	62	7.5	6.7	8.9	9.6
April 1943	−1.2	56	47	68	89	9.4	8.5	10.4	13.0
June 1945	−1.0	73	65	85	118	9.8	9.0	11.6	14.2
Aug. 1944	0.9	76	69	88	124	9.0	8.4	10.4	13.4
Oct. 1944	−1.3	57	47	72	89	9.4	8.1	10.9	12.5
Dec. 1943	−2.4	38	31	46	61	7.5	6.8	8.2	9.5

to approximate long-term mean conditions, months were selected during which the average surface temperature was close to the long-period normal. The selected months and their temperature departures from normal are shown in table 2. In order to obtain a diurnal curve, the net upward flux through the 1.5-km. surface was computed for the four times a day listed in table 2. The mean monthly temperature soundings for 2115 CST [2] were adjusted to the other three times a day by appropriate small modifications near the ground.

The choice of 1.5 km. as the level at which to compute B_a was made from figure 7. Here mean monthly night temperature soundings at Nash ille and Phoenix are plotted, together with dry adiabats through the mean monthly maximum temperature at the surface. If the latter approximate mean monthly midafternoon soundings, then the intersections of the two curves approximate the height to which heating and cooling are convected daily. The average pressure at the intersections of the six pairs of curves at Nashville is 860 mb., at a height of about 1.5 km. The data for Phoenix were added to figure 7 as a check on whether the Nashville soundings—monthly means including all weather conditions—were nonrepresentative of the desired condition of clear weather. Clear weather predominates a greater percentage of the time at Phoenix than at Nashville. The figure indicates that the two stations are similar to a satisfactory degree, and that therefore the Nashville monthly means are a reasonably good approximation of clear-weather means.

The ground temperature at Nashville for use on the radiation chart had to be estimated from the air temperature. Most of the present study was completed in 1947 before the recent great interest in micrometeorological studies of the surface layer of air and of soil temperatures in the United States. Guidance with respect to the relation of soil temperatures to air temperatures was obtained from two English investigations by Penman [13] and Johnson and Davies [7]. Penman obtained simultaneous continuous traces of soil temperature as close as practicable to the actual ground surface and of air temperature in a standard shelter. He found that during the hours of the day when the ground is cooling the air—from the time of the daily maximum of air temperature to sunrise—the ground temperature was typically only a degree or so (° C.) lower than the air temperature. Air and ground temperatures were assumed to be equal during those cooling hours in the present study and the mean monthly maximum and minimum air temperatures shown in table 2 and the mean "surface" (air) temperature at 2115 CST were substituted for ground temperatures at the appropriate times of day on the Elsasser chart.

During the warming hours of the day, Penman found that the ground is much hotter than the air. The ground temperature rises sharply from sunrise to solar noon when it may attain a value as much as 30° C. above the air temperature, then falls sharply until sunset.

An approximate relation of ground maximum daily temperature to the corresponding air maximum was obtained by plotting mean monthly ground and air maximum temperatures obtained by Johnson and Davies [7] at Salisbury Plain, England, against each other. The air temperature measurement by those investigators was in a standard shelter and the ground temperature 1 cm. below the surface of bare ground. The relationship was used to estimate Nashville mean monthly maximum ground temperature from the air maximum. The ground maximum was considered as occurring at local noon (1148 CST).

The net upward flux of long-wave radiation through the 1.5-km. surface, as computed from the Elsasser radiation chart, is shown in table 2 for the four times a day for the selected months. The intensity of the long-wave flux may be related as a matter of interest to something more personally familiar by comparison with insolation values in table 1. The intensity of this flux is of the same order of magnitude as the intensity of insolation on a horizontal surface about an hour after sunrise or before sunset.

Ground absorption, S.—To obtain estimates of the heat absorbed or released by the ground, profiles of ground temperature from the surface down to a depth of 30 cm. were constructed for every 2 hours throughout the day from Johnson and Davies' [7] tabulations of the mean annual diurnal range at various depths and the mean time of occurrence of the daily maximum at each depth. From these profiles a diurnal curve was constructed of the variation of the mean temperature of the 30-cm. layer, with temperatures expressed in terms of departure from the daily mean. The temperature departures were converted in turn to departures of the heat content of the ground by multiplying by the depth of the layer (30 cm.), and by the density and specific heat of soil. The density of earth was assumed to be 1.5 gm. cm.$^{-3}$, the value for dry packed earth from the Chemical Engineer's Handbook [14], and the specific heat was assumed to be 0.2 cal. deg.$^{-1}$ gm.$^{-1}$ from Brunt [1]. The only significant source of heat to the ground is by transmission through the surface. Therefore the rate of heat absorption by the ground, S, was obtained as the slope of the diurnal curve of heat content of the 30-cm. layer. The diurnal temperature cycle at 30 cm. was small enough to warrant ignoring any heat changes below that level. The foregoing procedure is very similar to that used by Williams for estimating the heat absorbed by the ground in the Phoenix-Las Vegas area.

The mean annual curve of values of S vs. time of day obtained as described above was modified subjectively for each of the 6 months under study in the following way. The curve was reshaped so as to place the maximum upward flux of heat at sunrise in each month instead of at the same hour throughout the year. This was done in such a way that the net area under each diurnal heating curve was zero. Secondly, all fluxes, both upward and down-

[2] Throughout this report, except in the forecast test, raobs at Nashville are considered as at 0915 CST and 2115 CST, the approximate mean time of observation during the years from which data were taken.

ward, were arbitrarily diminished slightly in magnitude for December, in consideration of the small diurnal range of air temperature in that month.

Usually the most important variable controlling the heat absorbed by the ground is the moisture content of the soil. This affects not only the density and specific heat but the conductivity as well. Detailed consideration of soil types is not warranted unless some index of the moistness is also used. Neither moisture content nor soil type was taken into account in the present study. This is not disastrous because the flux of heat into the ground is smaller than the other fluxes in any case.

Evaporation, E.—Hourly values of evaporation from the ground plus transpiration from plants were derived for Nashville by subdividing an estimate of the mean annual total evapotranspiration at Nashville successively into monthly, daily, and hourly amounts.

The mean annual evapotranspiration at Nashville was assumed to be 20 inches. This quantity is intermediate between values of the annual evapotranspiration obtained by different methods. Kittredge [9] and Wilm and Thornthwaite [20] show maps of annual evapotranspiration estimated by subtracting runoff of streams from precipitation. A series of direct measurements of evaporation were made in 1939 by Thornthwaite and Holzman [16] [17] over a field at Arlington, Va., by the turbulent transport method. With interpolation for missing months of February and September, an annual total evapotranspiration of 11.72 inches was obtained for that location. Kittredge's and Thornthwaite's maps show 25 and 28 inches annual evapotranspiration at Arlington, Va., and 31 and 30 inches at Nashville. A value of 20 inches annual evapotranspiration at Nashville is intermediate between the two kinds of measurements.

The Thornthwaite-Holzman Arlington data were used directly by Neiburger. Williams, in view of the climate of his region, ignored evaporation.

The Arlington measurements were considered the best available indication of the annual march of evapotranspiration. Monthly percentages of the annual evapotranspiration during the single year of observations (1939) were smoothed out somewhat for this study. The observed and smoothed percentages are shown in table 3. Some evaporation pan measurements in the southeastern United States showed about the same annual distribution of evaporation. Daily values were obtained by dividing monthly values by 30. The daily energy requirement to produce this evaporation is computed using a value of 590 calories per gram as the latent heat of vaporization.

TABLE 3.—*Monthly and daily evapotranspiration, Nashville, Tenn.*

	Monthly percentage of annual evapotranspiration		Monthly evaporation (inches) [2]	Daily evaporation (inches)	Daily energy requirement (langleys)
	Unsmoothed [1]	Smoothed			
January	3	3	0.6	0.020	30
February	[3] 5	5	1.0	.033	50
March	8	8	1.6	.053	80
April	6	10	2.0	.067	100
May	13	13	2.6	.087	130
June	19	15	3.0	.100	150
July	14	14	2.8	.093	140
August	11	11	2.2	.073	110
September	[3] 8	8	1.6	.053	80
October	5	5	1.0	.033	50
November	3	4	.8	.027	40
December	4	3	.6	.020	30

[1] After Thornthwaite and Holzman [16] [17].
[2] Annual total assumed 20 inches.
[3] Interpolated.

The Arlington data were again used as the standard for the distribution throughout the day of the daily total evapotranspiration with certain necessary substitutions of one month for another. Thornthwaite and Holzman measured the specific humidity and the wind speed at two levels; the evaporation was then computed from the equation,

$$E=0.63\frac{k_0^2\,(q_1-q_2)\,(u_2-u_1)}{\left(\ln\frac{z_2}{z_1}\right)^2},$$

where E is the total evaporation in inches over a time interval, k_0 is von Kármán's constant, q_1 and q_2 are the specific humidities at the two levels in grams of moisture per cubic meter of air, u_1 and u_2 are the total wind movement in miles at the lower and upper levels over the time interval, z_2/z_1 is the ratio of the height of the two levels above a reference height h_0. Thornthwaite and Holzman did not publish hourly values of evaporation but rather listed hourly values of specific humidity, temperature, and wind at the different levels, together with monthly means by hours for the months of January and March through August. The percentage of the daily evaporation that occurs in each of the 24 hours of the day was computed by assuming that the evapotranspiration is proportional to the product (q_1-q_2) times (u_2-u_1), the other factors in the equation being constants. The hourly percental distribution of the daily evaporation for January, April, June, and August 1939 obtained in this way (table 4 labeled "1939") were applied to the daily evapotranspiration energy requirements to estimate hourly energy requirements (table 5). The hourly values in tables 4 and 5 do not form a smooth series because values of the wind-speed difference (u_2-u_1) on which they are based were expressed to one significant figure only and did not form a smooth series. Smoothing was introduced when a diurnal curve was plotted.

Another method of estimating hourly distribution of evaporation is based on the assumption that the evaporation is proportional to the difference between the actual vapor pressure and the saturation vapor pressure. The daily distribution of evaporation estimated by this method for Washington in April and June is shown, for comparison, in table 4, under the heading "V. P." The basic data used, hourly temperature and dewpoint normals for Washington, are those published on the back of the Weather Bureau *Daily Weather Map*. It is seen that the vapor pressure method gives a distribution essentially the same as the other method, except in the early night hours when the evaporation has been diminished by a decrease

TABLE 4.—*Hourly percental distribution of daily evaporation, Arlington, Va. 1939 percentages computed from turbulent transport measurements; V. P. (vapor pressure) percentages computed from dewpoints*

Hour ending (EST)	Jan. 1939	April 1939	April V. P.	June 1939	June V. P.	Aug. 1939
a. m.						
1	2.9	2.7	3.0	2.0	2.3	0.5
2	2.6	2.9	2.6	1.9	1.9	0.0
3	2.8	4.2	2.3	1.4	1.9	−0.5
4	0.0	2.6	2.3	1.4	1.5	0.0
5	2.8	1.2	2.1	1.5	1.8	−0.4
6	3.3	2.7	2.0	2.0	1.5	0.0
7	0.0	2.5	2.0	3.2	1.5	0.9
8	2.9	1.4	2.3	4.0	2.2	2.5
9	3.2	1.6	2.6	3.5	2.9	3.8
10	3.2	3.8	3.5	4.8	2.7	5.4
11	3.6	2.0	4.2	5.2	4.9	6.0
12	7.7	6.2	4.7	6.2	5.8	7.8
p. m.						
1	8.0	9.5	5.4	6.7	6.7	7.7
2	4.1	7.7	6.2	8.4	7.2	9.3
3	8.0	6.9	6.6	7.7	7.7	8.4
4	8.2	2.2	7.0	6.8	7.7	11.1
5	8.0	4.1	7.0	6.3	7.7	8.5
6	7.7	4.1	7.0	6.1	6.9	6.7
7	6.1	5.0	6.2	4.7	6.5	5.4
8	3.2	6.7	5.2	4.5	5.2	4.2
9	3.2	4.6	4.8	3.7	4.3	4.7
10	2.9	4.5	4.1	3 6	3.5	2.9
11	2.8	6.5	3.4	2.2	3.5	1.9
12	3.0	4.3	3.1	2.0	2.6	1.4

TABLE 5.—*Hourly evapotranspiration energy requirement, Nashville, Tenn. (unsmoothed estimates)*

Hour ending (local time)	Langleys					
	February [1]	April	June	August	October [2]	December [1]
a. m.						
1	1.4	2.7	3.0	0.6	1.4	0.9
2	1.3	2.9	2.8	0.0	1.5	0.8
3	1.4	4.2	2.1	−0.6	2.1	0.8
4	0.0	2.6	2.1	0.0	1.3	0.0
5	1.4	1.2	2.2	−0.4	0.6	0.8
6	1.6	2.7	3.0	0.0	1.4	1.0
7	0.0	2.5	4.8	1.0	1.2	0.0
8	1.4	1.4	6.0	2.7	0.7	0.9
9	1.6	1.6	5.2	4.2	0.8	1.0
10	1.6	3.8	7.2	5.9	1.9	1.0
11	1.8	2.0	7.8	6.6	1.0	1.1
12	3.8	6.2	9.3	8.6	3.1	2.3
p. m.						
1	4.0	9.5	10.0	8.5	4.8	2.4
2	2.0	7.7	12.6	10.2	3.8	1.2
3	4.0	6.9	11.6	9.2	3.5	2.4
4	4.1	2.2	10.2	12.2	1.1	2.5
5	4.0	4.1	9.4	9.3	2.0	2.4
6	3.8	4.1	9.2	7.4	2.0	2.3
7	3.0	5.0	7.0	5.9	2.5	1.8
8	1.6	6.7	6.8	4.6	3.4	1.0
9	1.6	4.6	5.6	5.2	2.3	1.0
10	1.4	4.5	5.4	3.2	2.2	0.9
11	1.4	6.5	3.3	2.1	3.2	0.8
12	1.5	4.3	3.0	1.5	2.2	0.9

[1] Derived from January hourly distribution (table 4).
[2] Derived from April hourly distribution (table 4).

in the wind velocity while the vapor pressure difference is still relatively high. Thornthwaite and Holzman's evaporation measurement site was on the outskirts of Washington.

Heat Balance Diagram.—Local heat balance diagrams for alternate months from February through December (figs. 1–6) were constructed from the data described above and are a graphical portrayal of equation (4). The various curves on these figures show, for the 15th day of each month, the diurnal progression of insolation I_0 (from table 1), the reflection of a portion of the insolation RI_0 (20 percent), the net outgoing long-wave radiation from the top of the diurnally heated layer B_a (table 2), the heat used in evaporation of water from ground and plant surfaces LE (table 5), the energy used to warm the ground or given up by cooling ground S, and finally, the heat H entering the air and raising its temperature or given up by the air as it cools. The air curve is constructed by adding together algebraically at each hour the ordinates of all the other curves, that is, by performing the operation indicated by equation (4). The air curves depict estimates of climatological values of the heating or cooling of air at Nashville in clear weather. The amount of heat that should be added to the lower end of a raob to predict a later maximum temperature is obtained by integrating the area under the curve between the hours of the raob and the expected maximum temperature. (In this procedure the net area below the zero line is subtracted from the net area above the zero line.) Integrating under the entire air curve gives the net daily clear-weather heating; that is, the excess of a day's sunshine over the energy-dissipating processes for 24 hours.

3. HEATING AND COOLING VALUES FROM RAOBS

Values of clear-weather heating and cooling at Nashville were obtained by comparing successive temperature soundings. In addition to the twice-daily raobs a hypothetical midafternoon sounding was constructed by running a dry adiabat from the maximum temperature for the day up to the intersection with the previously observed temperature curve. The apparent heating or cooling from one temperature sounding to the next was measured on an adiabatic chart and converted to calories in a vertical column of 1 square centimeter cross section. This was done for all instances of cloudless sky during a 21-month period.

Definition of periods of the day.—The 24-hour day was divided into three parts: from the time of morning raob to time of maximum afternoon temperature, approximately 0915 to 1600 CST, called the "day" period; from the time of afternoon maximum temperature to the time of the night raob, approximately 1600 to 2115 CST, called the "evening" period; and from night raob to morning raob, approximately 2115 to 0915 CST, termed the "night" period.

Heating for day period.—The clear-weather days from January 1945 through September 1946 were selected by inspection of 3-hourly surface weather maps, with the following requirement: One-tenth or less of sky covered by cirrus or altocumulus, otherwise no clouds, at 0630, 0930, 1230, and 1530 CST. An original criterion of 100 percent sunshine by triple register measurement was rejected as it was found that thin cloudiness could appreciably reduce the daily insolation even with reported 100 percent sunshine. The morning (0915 CST) raobs together with a dry adiabat through the afternoon maximum temperature were plotted on adiabatic charts for 54 clear days. The maximum temperature was plotted at the surface pressure of the morning raob. The area on the

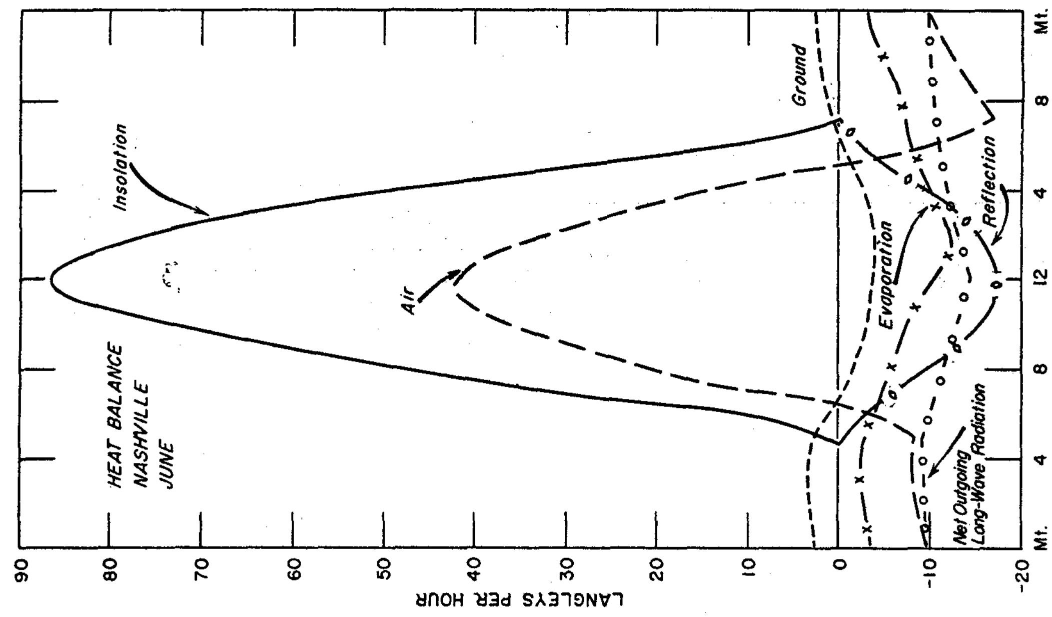

FIGURE 3.—Heat balance diagram for Nashville for June.

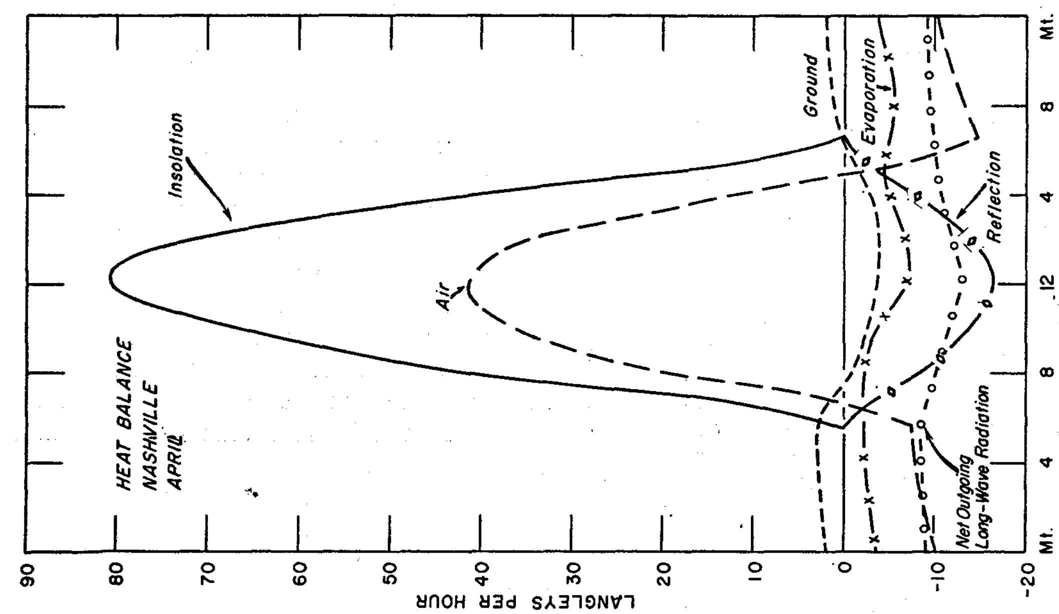

FIGURE 2.—Heat balance diagram for Nashville for April.

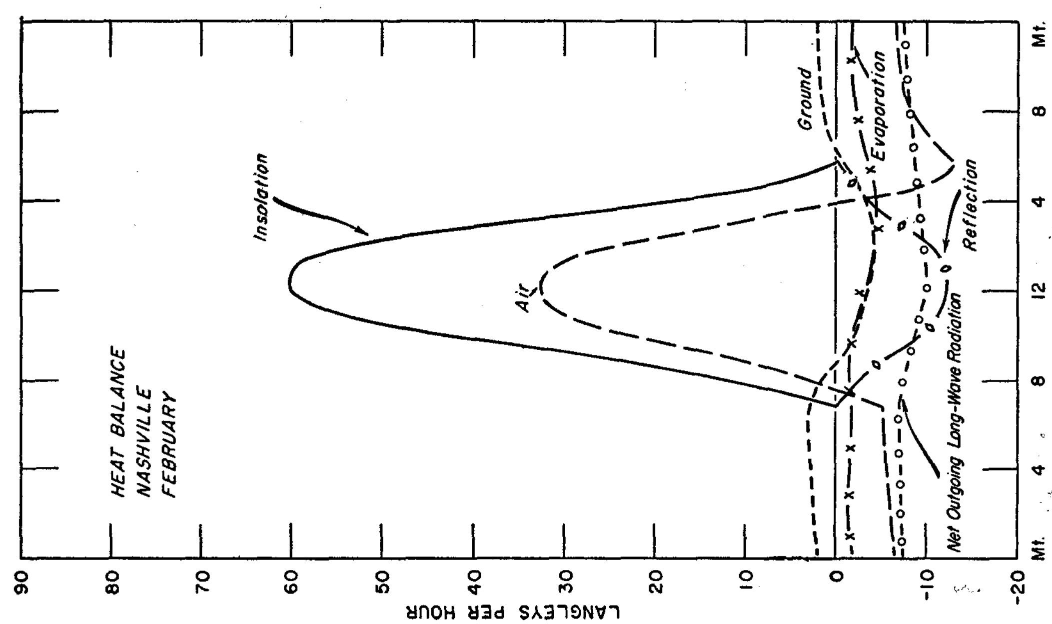

FIGURE 1.—Heat balance diagram for Nashville for February.

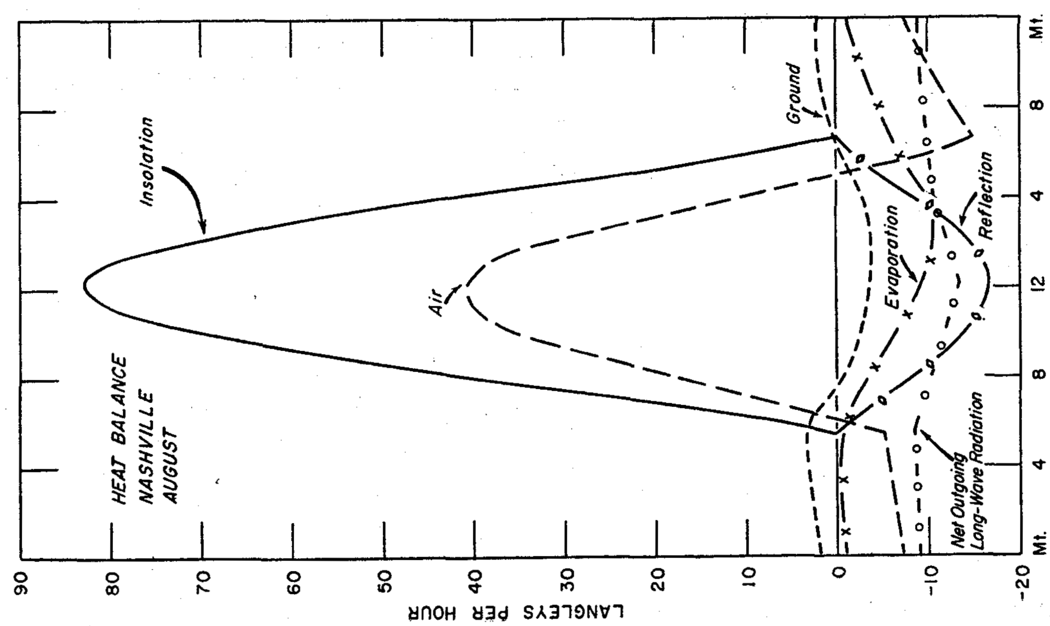

FIGURE 4.—Heat balance diagram for Nashville for August.

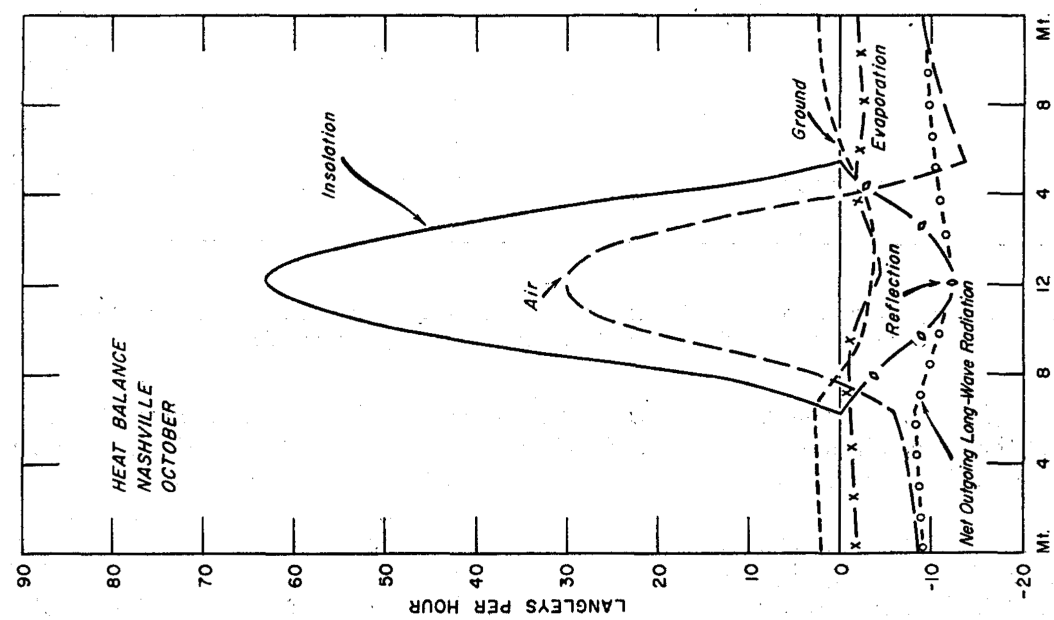

FIGURE 5.—Heat balance diagram for Nashville for October.

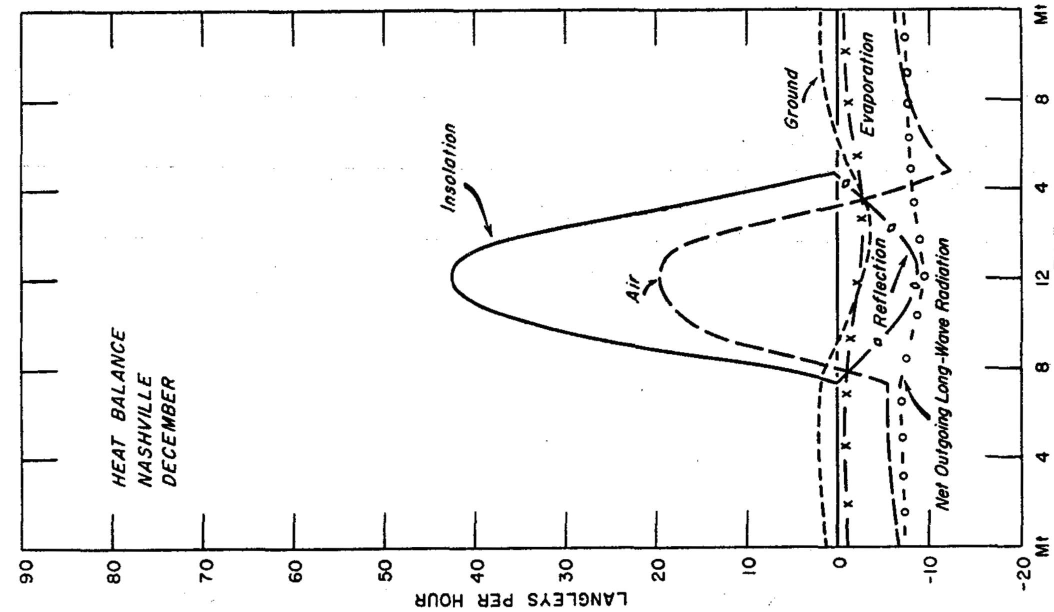

FIGURE 6.—Heat balance diagram for Nashville for December.

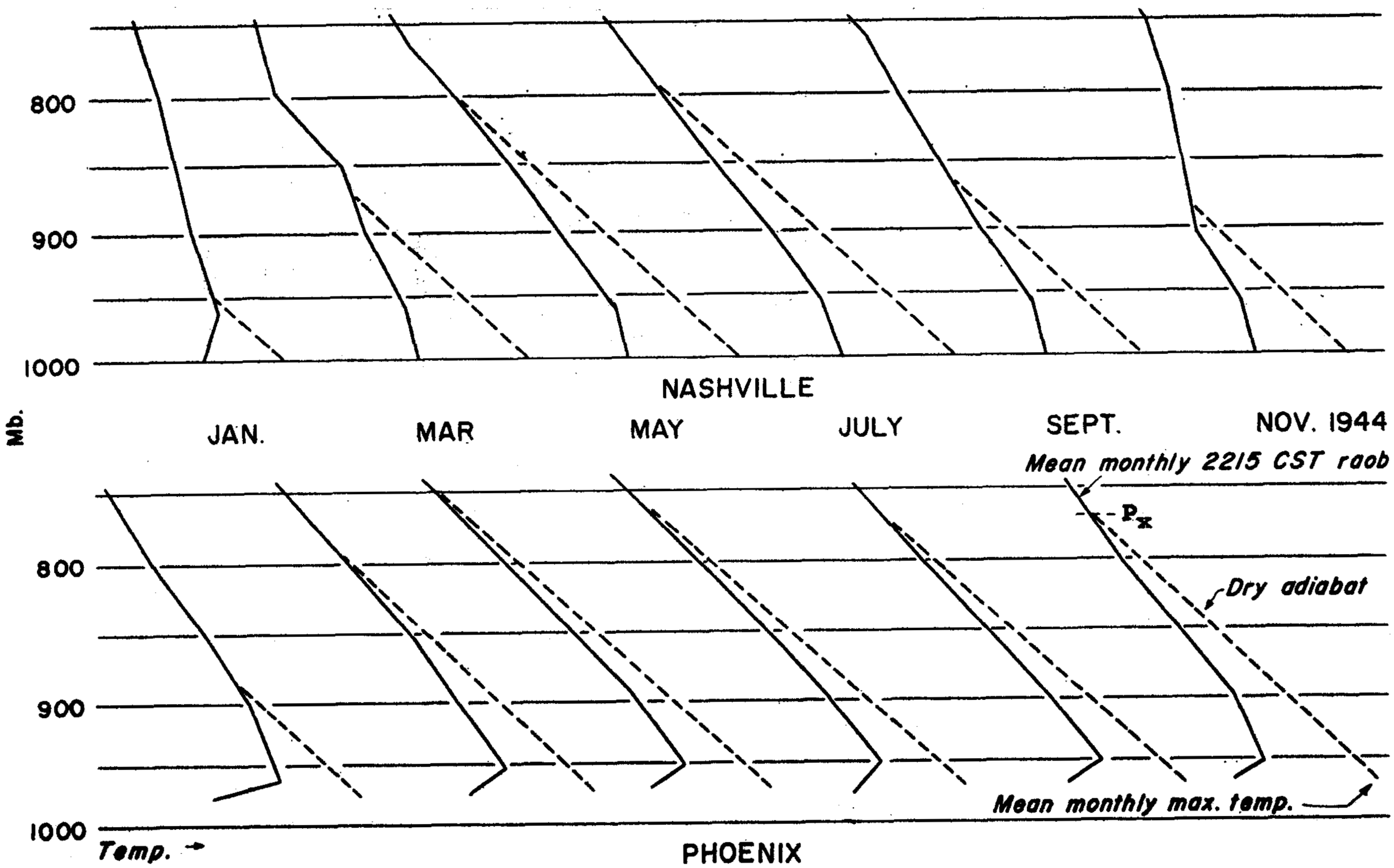

FIGURE 7.—Mean monthly night temperature soundings (solid) together with dry adiabats through the mean monthly maximum temperature at the surface (dashed) for Nashville, Tenn. and Phoenix, Ariz.

adiabatic chart between the morning sounding and the dry adiabat represented the change in heat content H_a of the column of air at Nashville from 0915 to about 1600 CST.

An attempt was made to separate the local heating, H, from the advected heat, A, (equation (3)) by "advecting" the 0915 CST sounding. The isotherms that would arrive over Nashville by a 6-hour movement of the geostrophic wind were identified on the 0915 CST 850-mb. and 700-mb. charts. The temperatures of these isotherms were plotted on the adiabatic chart at 850 mb. and 700 mb., respectively. At the surface the 6-hour geostrophic advection was estimated on the 1230 CST map. The surface point of the 0915 CST raob was displaced to the right or the left by this amount. After plotting the three advected temperatures on the adiabatic chart as illustrated in figure 8 a complete advected sounding was constructed by assuming that the advection varied linearly from one plotted level to another.

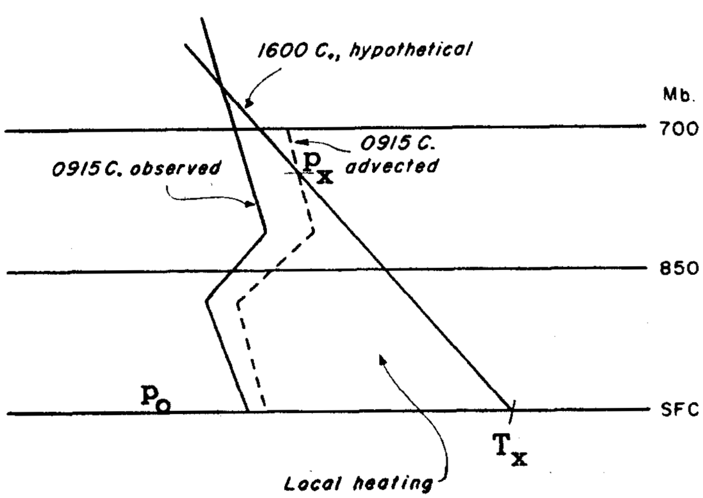

FIGURE 8.—Graphical determination of heating for day period.

The heat equivalent of the area between the advected sounding and the hypothetical 1600 CST sounding (fig. 8) was the estimate of the local heating. This heat equivalent, H, may be computed from:

$$H=(c_p/g)\ (p_0-p_x)\ (\overline{T}_x-\overline{T}_1) \tag{5}$$

where c_p is the specific heat of air at constant pressure, g the acceleration of gravity, p_0 the surface pressure, p_x the pressure at the intersection of the advected morning sounding and the hypothetical afternoon sounding, and $\overline{T}_x$ and $\overline{T}_1$ the mean temperatures respectively of those soundings between p_0 and p_x. Expressing H in calories, pressures in millibars, temperatures in ° C. and considering g as 1000 cm. sec. $^{-2}$, this becomes:

$$H=.239\ (p_0-p_x)\ (\overline{T}_x-\overline{T}_1) \tag{6}$$

Table 6.—*The heat (langleys) absorbed by the air from 0915 to 1600* cst, *(day period), Nashville, Tenn.*

Date	*H*		Date	*H*		Date	*H*	
	Adjusted for advection	Unadjusted		Adjusted for advection	Unadjusted		Adjusted for advection	Unadjusted
Jan. 5, 1945	90	165	May 5, 1946	227	227	Sept. 3, 1945	226	205
Jan. 10, 1945	98	140	May 8, 1945	254	160	Sept. 11, 1946	149	140
Jan. 11, 1945	115	160	May 22, 1946	196	196	Sept. 25, 1946	155	155
Jan. 26, 1945	151	115	May 23, 1945	231	160	Sept. 26, 1946	168	168
						Sept. 30, 1946	172	120
Mean: 13	114	148	Mean: 14	228	156	Mean: 19	174	158
Jan. 31, 1945	177	115	June 4, 1946	194	180	Oct. 2, 1946	220	200
Feb. 1, 1946	139	235	June 5, 1946	237	290	Oct. 3, 1946	219	200
Feb. 2, 1946	108	175	June 6, 1946	107	140	Oct. 4, 1946	181	160
Feb. 20, 1946	172	140	June 23, 1946	305	270	Oct. 5, 1946	268	250
						Oct. 26, 1945	192	145
Mean: 6	150	166	Mean: 10	211	220	Mean: 8	216	191
Mar. 3, 1946	171	240	July 16, 1945	157	120	Nov. 5, 1945	117	170
Mar. 22, 1945	176	210	July 22, 1944	333	333	Nov. 15, 1945	208	208
Mar. 27, 1945	92	110	July 23, 1946	176	176	Nov. 20, 1945	86	105
Mar. 31, 1946	254	215	July 26, 1946	199	120	Nov. 24, 1945	57	130
Apr. 5, 1946	219	200				Nov. 29, 1946	138	125
Mean: 24	182	195	Mean: 22	216	157	Mean: 19	121	148
Apr. 5, 1945	251	220	Aug. 18, 1945	204	195	Dec. 12, 1945	179	160
Apr. 13, 1946	144	185	Aug. 26, 1945	251	195	Dec. 16, 1945	145	190
Apr. 18, 1946	196	196	Aug. 27, 1945	190	200	Dec. 20, 1945	48	100
Apr. 19, 1945	141	210	Aug. 27, 1946	189	200	Dec. 21, 1945	80	80
Apr. 19, 1946	197	220	Aug. 31, 1946	224	250			
Mean: 15	186	206	Mean: 26	212	188	Mean: 17	113	132

H was evaluated from the 54 adiabatic charts for clear-weather days from the above equation. The values are listed in table 6 together with monthly means. The monthly means are plotted in figure 9 and an annual curve was fitted by eye. The curve was drawn so as to be symmetrical about the summer solstice on June 22.[3]

[3] Making the curve symmetrical about June 22 was a practical expedient for fitting a curve to the data. It is by no means certain that it should be symmetrical. Possibly the curve should have been drawn closer to the high point for October. Dryer ground at that season would in part lead to a higher value of *H* than at the corresponding time in early spring.

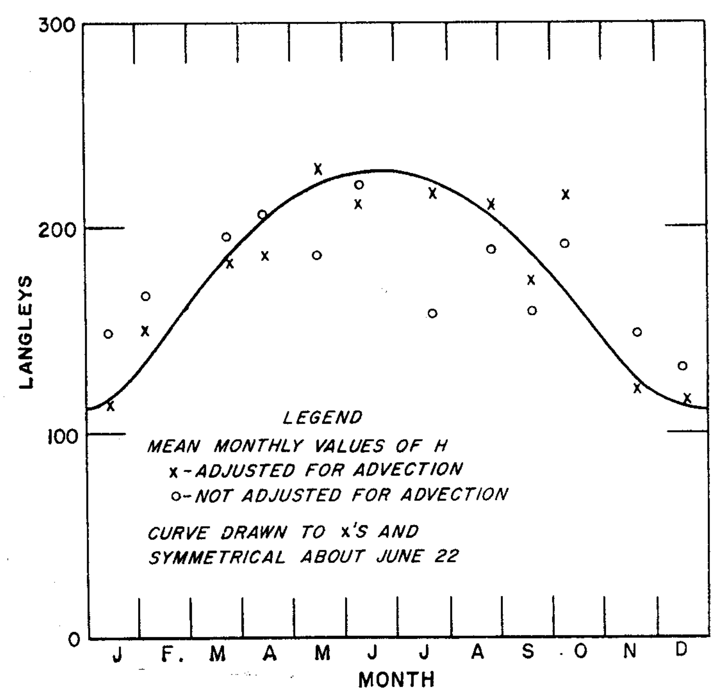

Figure 9.—Net local clear weather heating for day period (0915–1600 cst) for Nashville.

Values of *H* corresponding to the area between the morning 0915 cst sounding without adjustment for advection and the afternoon dry adiabat are also listed in table 6 and the monthly means plotted in figure 9. It can be seen that both sets of values of *H* fit the same curve except in winter, indicating that in general the net effect of application of the advective correction is small. This results in part from the character of the sample, cloudless days; on many of these Nashville was near the center of a High, where light winds prevailed.

Cooling for evening period.—The heat equivalent *H*, was evaluated for the evening period, from the time of maximum temperature to the 2115 cst raob, by methods strictly analogous to those used for the day period. There were 57 clear-weather cases, selected on the basis of lack of cloudiness at Nashville on the 1530, 1830, and 2130 cst surface maps. Since advective corrections were shown to have no great effect for the day period, it was assumed that $A=0$ for the first evaluation of *H*. These values are listed in table 7 and monthly means are plotted in figure 10, together with an eye-fitted curve. The shape of this curve was surprising, the greatest cooling being indicated for the months of longest daylight. To check on the curve, values of *H* were recomputed with the advective correction applied. These are also listed in table 7 and monthly means plotted in figure 10. It is seen that the original shape of the curve was not materially modified by the advective correction.

The time of day of the maximum temperature at Nashville was checked to ascertain whether any seasonal trend in this time could have affected the curve of figure 10. It was found during one year that the monthly average time of the daily maximum temperature varied between 1545 and 1612 cst, with no systematic seasonal progres-

TABLE 7.—*The heat (langleys) released by the air from 1600 to 2115* CST. *(evening period) Nashville, Tenn.*

Date	H: Adjusted for advection	H: Unadjusted	Date	H: Adjusted for advection	H: Unadjusted	Date	H: Adjusted for advection	H: Unadjusted
Jan. 1, 1946	64	80	May 18, 1946	144	105	Sept. 11, 1945	123	160
Jan. 4, 1946	90	35	May 20, 1945	96	60	Sept. 11, 1946	158	175
Jan. 17, 1946	75	55	May 22, 1945	94	155	Sept. 25, 1946	108	140
Jan. 27, 1946	34	34	May 22, 1946	144	115	Sept. 26, 1946	155	155
Jan. 31, 1946	65	155	May 23, 1945	143	110	Sept. 30, 1946	113	135
Mean: 16	66	72	Mean: 21	124	109	Mean: 21	131	153
Feb. 1, 1946	78	75	June 4, 1946	182	220	Oct. 2, 1946	214	215
Feb. 2, 1946	88	40	June 5, 1946	162	170	Oct. 3, 1946	152	155
Feb. 6, 1946	38	100	June 6, 1946	169	55	Oct. 4, 1946	171	180
Feb. 23, 1945	40	40	June 7, 1946	164	105	Oct. 5, 1946	184	195
			June 21, 1946	192	155	Oct. 16, 1945	61	85
Mean: 8	61	64	Mean: 9	174	141	Mean: 8	156	166
Mar. 2, 1946	164	40	June 23, 1946	293	290	Nov. 5, 1945	93	65
Mar. 11, 1946	72	35	July 6, 1946	111	110	Nov. 14, 1945	62	60
Mar. 20, 1946	52	50	July 16, 1945	138	145	Nov. 15, 1945	84	55
Mar. 30, 1946	141	100	July 22, 1944	229	230	Nov. 24, 1945	72	25
Apr. 2, 1946	139	155	July 26, 1946	172	205			
Mean: 19	114	76	Mean: 13	189	196	Mean: 14	78	51
Apr. 4, 1946	30	180	Aug. 26, 1946	201	200	Dec. 7, 1945	23	35
Apr. 12, 1946	37	75	Aug. 27, 1945	72	72	Dec. 16, 1945	105	95
Apr. 17, 1946	78	80	Aug. 30, 1946	176	205	Dec. 20, 1945	35	30
Apr. 18, 1946	96	95	Aug. 31, 1945	176	175	Dec. 22, 1946	35	25
Apr. 19, 1946	106	95				Dec. 26, 1945	73	85
Mean: 14	69	105	Mean: 28	125	163	Mean: 18	54	54

sion. (Days with maximum temperature before 1 p. m. or after sunset were excluded.) The time of maximum temperature on the specific days for which H was evaluated was also examined and no seasonal trend found.

Cooling for night period.—The heat equivalent H, was evaluated for 58 clear-weather periods between the 2115 and 0915 CST raobs. A pressure surface had to be designated as the top of the layer in which H would be computed. This was placed at 850 mb., corresponding to the 1.5-km. level for which B_a was computed.

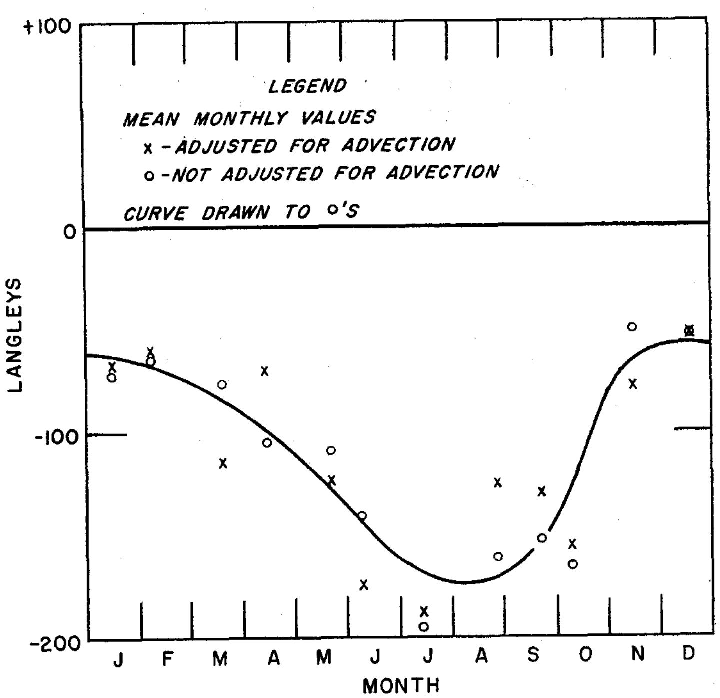

FIGURE 10.—Net local clear weather heating for evening period (1600–2115 CST) for Nashville.

Advective corrections were determined for the night period by assuming that the observed change in temperature at 850 mb. from one raob to the next was all due to advection and that the magnitude of the advection was constant from the ground up to this level. H could then be computed from the following simplification of equation (6):

$$H=(.239)(150)(\overline{T}_1-\overline{T}_2-\Delta T_a) \tag{7}$$

where $\overline{T}_1$ is the mean temperature between the surface and 850 mb. at 2115 CST, $\overline{T}_2$ the mean temperature at 0915 CST and ΔT_a the change in temperature at 850 mb. over this period (all in ° C.). In equation (6) (p_0-p_x) is set equal to 150 mb., the slight fluctuation of the Nashville surface pressure about 1000 mb. being neglected. The values of H from equation (7) are listed in table 8 and plotted in figure 11, together with an eye-fitted curve.

Several more complex ways of applying the advective corrections were experimented with to find if they improved the scatter of the values of H. None appeared to be superior to the simple method used and some were inferior. These other methods included geostrophic advection of the observed mean surface-to-850-mb. temperature, mean of geostrophic advection on the initial and final 850-mb. charts, mean temperatures advected by the observed 3000-ft. winds, and variations of these.

4. COMPARISON OF VALUES OF HEATING AND COOLING BY THE TWO METHODS

Values of the heating or cooling during the day, evening, and night periods by the heat-balance method were obtained by planimetering the area under the air curve

TABLE 8.—*The heat (langleys) absorbed by the air from 2115 to 0915 CST, (night period) Nashville, Tenn. Advective corrections included in computation of H*

Date	H	Date	H	Date	H
Jan. 5, 1945	4	May 6, 1945	4	Sept. 3, 1945	0
Jan 11, 1945	−132	May 22, 1946	−4	Sept. 4, 1945	0
Jan. 24, 1945	−75	May 23, 1945	−25	Sept. 5, 1946	11
Jan. 31, 1945	−18	May 24, 1945	−14	Sept. 13, 1946	−14
		May 29, 1946	−47	Sept. 27, 1946	64
Mean: 18	−55	Mean: 21	−17	Mean: 10	12
Feb. 2, 1946	−32	June 4, 1946	−72	Oct. 1, 1946	−21
Feb. 15, 1945	−111	June 5, 1946	11	Oct. 2, 1946	−18
Feb. 23, 1945	−25	June 7, 1946	72	Oct 3, 1946	47
Feb. 24, 1945	−36	June 8, 1946	58	Oct. 4, 1946	−4
Mar. 1, 1946	50	June 9, 1946	0	Oct. 13, 1946	−18
Mean: 19	−31	Mean: 7	14	Mean: 5	−3
Mar. 3, 1946	−61	June 23, 1946	14	Nov. 5, 1945	−107
Mar. 9, 1945	18	July 16, 1945	−29	Nov. 15, 1945	−125
Mar. 12, 1946	4	July 16, 1946	−29	Nov. 16, 1945	4
Mar. 27, 1945	−11	July 17, 1945	104	Nov. 24, 1945	−89
Mar. 28, 1945	−21	July 23, 1946	−82	Nov. 26, 1945	−50
Mean: 16	−14	Mean: 13	−4	Mean: 17	−73
Apr. 3, 1946	−50	Aug. 27, 1946	−25	Dec. 8, 1945	−68
Apr. 5, 1946	−72	Aug. 28, 1945	−4	Dec. 21, 1945	−39
Apr. 7, 1945	−25	Aug. 29, 1945	25	Dec. 22, 1946	21
Apr. 18, 1946	18	Aug. 31, 1945	11	Dec. 23, 1946	14
Apr. 19, 1946	−18	Aug. 31, 1946	21		
Mean: 10	−29	Mean: 29	6	Mean: 18	−18

in figures 1 to 6 between the hours of 0915 and 1600 CST, 1600 and 2115 CST, and 2115 and 0915 CST. These are compared with the curves for H from raobs in figure 12. The correspondence between the two curves for the night and the day periods is gratifyingly close; for the evening period the difference is surprisingly great.[4]

Difference in placement of the top of the layer from which the cooling was computed was eliminated as an important cause of the disparity between the two evening period curves. The long-wave radiational loss for the heat-balance diagrams was computed at the 1.5-km. surface. The top of the cooled layer on the adiabatic charts for the evening period, was frequently at a higher elevation than 1.5 km. To determine the order of magnitude of additional upward long-wave radiation from moist layers above 1.5 km., the flux for the mean June 1945 sounding was computed through the 3-km. surface on the Elsasser chart. The comparative data are:

Flux through 1.5-km. surface 29 ly/3 hr.
Flux through 3-km. surface 35 ly/3 hr.

It is seen that the additional increment of radiational flux between 1.5 and 3 km. over a 6-hour period would rarely exceed about 12 langleys, only a fraction of the discrepancy between the two evening period H curves.

If the lapse rate at the time of maximum temperature were appreciably superadiabatic the effect of assuming an adiabatic lapse rate in this study would be to exaggerate both the cooling during the evening period and the heating during the day period. Improvement of the correspondence of the curves of figure 12b by constructing superadiabatic lapse rates would be at the expense of the good fit of the curves of figure 12a.

[4] It is perhaps worth placing in the record that the H curves from raobs in figures 8, 9, and 11, which are subjectively drawn to scattered data, were constructed *before* the more objective corresponding heat-balance curves, with no prior knowledge of what the shape or level of the heat-balance curves would be.

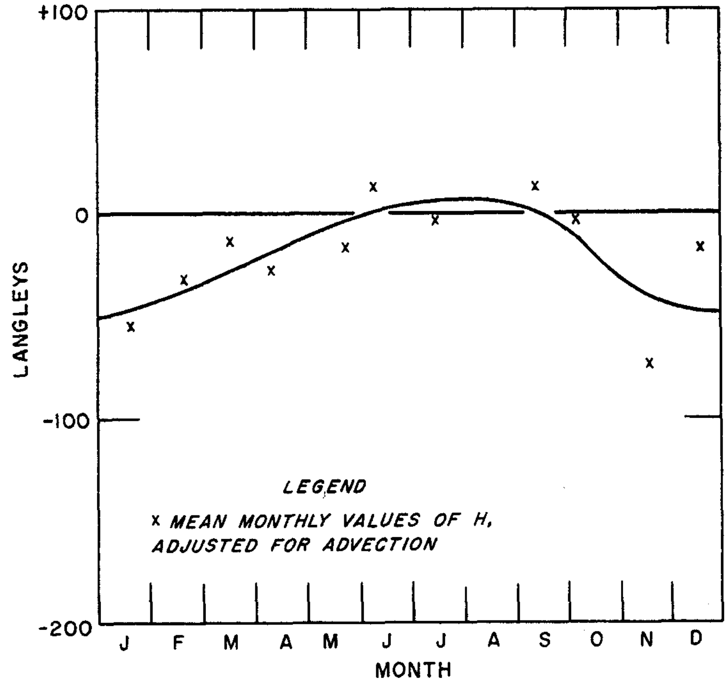

FIGURE 11.—Net local clear weather heating for night period (2115–0915 CST) for Nashville.

Another factor to take into account is that the heat-balance curve of figure 12b is for mean soundings while the raob curve is for selected clear-weather cases. It is reasonable to suppose that the mean moisture content would be lower for the latter than for the overall mean. The net upward long-wave radiation, B_a, could be greater for the drier cases because of less return downward radiation from above the level where B_a was determined.

None of the foregoing seems to be a fully adequate explanation of the discrepancy of figure 12b. Resolving the discrepancy awaits more data of this nature from other investigators.

5. MAXIMUM TEMPERATURE FORECASTS

Values of H for maximum temperature forecast.—The idea with which this investigation started was to develop values of the heating area to add to the night raob for predicting the maximum temperature the next afternoon. This value is the sum of H for the night period and for the day period. Curves of this sum are shown in figure 12. Lacking a reason for choosing one curve over the other, the average of the two curves (dashed on the figure) was selected for forecasting. The heat H (in langleys) read from the curve for a particular date is converted to a triangular area on the adiabatic chart by use of equation (6) converted to the form:

$$H = .239\Delta p(\Delta T/2) \tag{8}$$

Δp and ΔT are the legs of a triangle on the adiabatic chart as shown in figure 13, scaled in millibars and ° C. respectively. Another equation in Δp and ΔT is:

$$\Delta p = K\Delta T \tag{9}$$

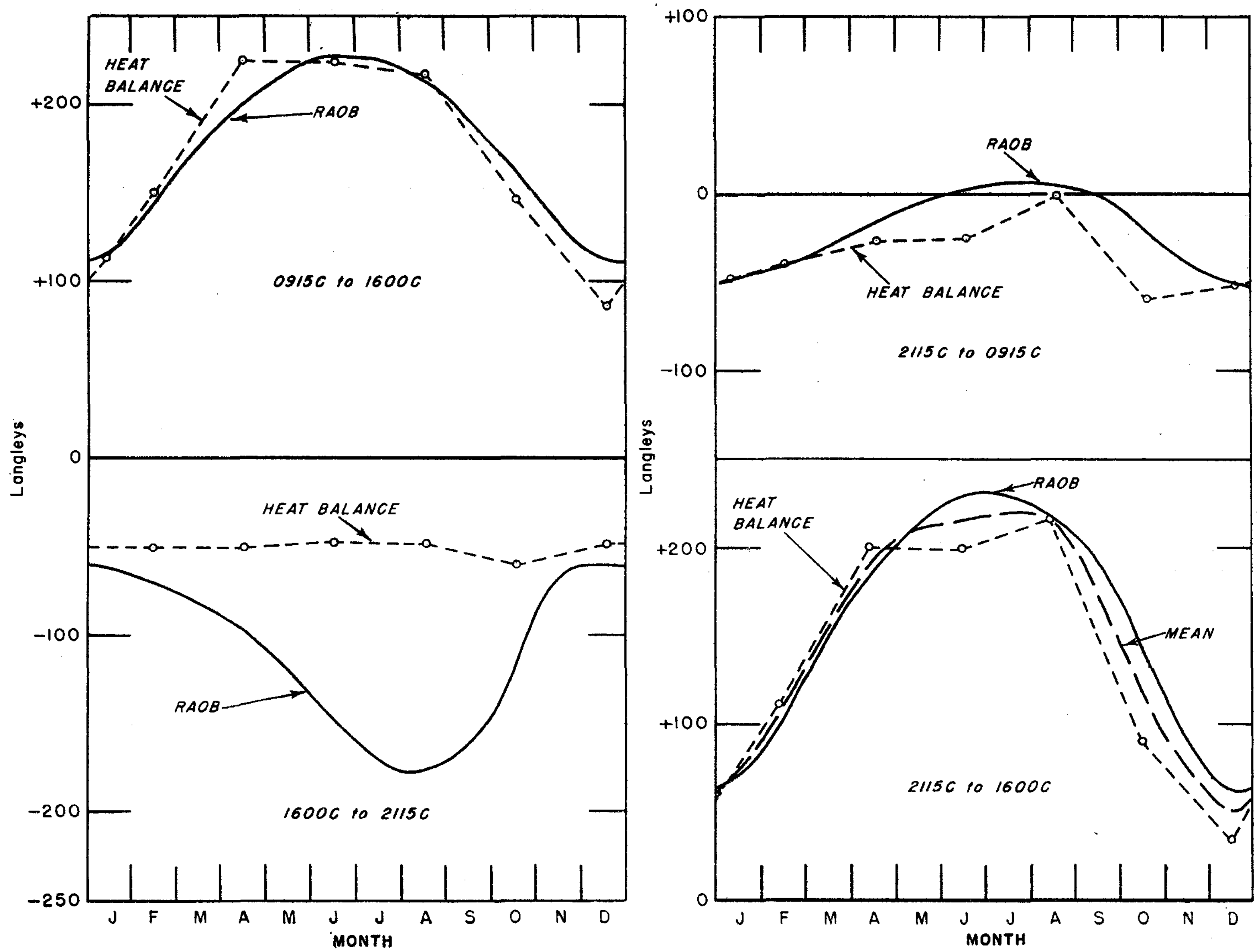

FIGURE 12.—Heating or cooling of air in clear weather, Nashville. Curves marked "heat balance" were obtained by planimetering the area under the air curve in figures 1–6.

K is evaluated by constructing any triangle similar to the one in figure 13 in the region of the adiabatic chart to be used, and depends on the slope of the dry adiabats. Solving the simultaneous equations (8) and (9) yields specific values of Δp and ΔT for laying out the triangle of the desired area corresponding to H. This may be done on a transparent overlay. The H area is then added graphically to the raob temperature curve to obtain the maximum temperature forecast in the familiar manner shown in figure 14. A permanent transparent overlay may be constructed on which various H values are represented by triangles having two sides coincident and the third side as a family of parallel lines labeled with the H values.

Test of forecasting curve.—The mean curve of the lower right panel of figure 12 was applied to forecasting the maximum temperature at Nashville from the raob of the night before for each day from March 1 through November 30, 1954. The winter months were omitted so as not to confound the results with too many days when the radiative balance was relatively unimportant as compared with advection. These were after-the-fact forecasts but were made in a strictly objective manner. Two departures from field forecast conditions were permitted so as not to introduce subjective elements. First, no adjustment was made for advection. Second, observed cloudiness instead of forecast cloudiness was used in making an allowance for reduction of insolation. Completely cloudless days are few in number. The intent in designing this test was not only to obtain an idea of the forecast accuracy for near-cloudless days but also an idea of the amount of cloudiness that could be tolerated in applying this technique. Therefore, a forecast was made for every day during the forecast period. It turned out that on the average the forecast errors for cloudy days were not appreciably larger than for clear days. Therefore all days were included in the final verification statistics.

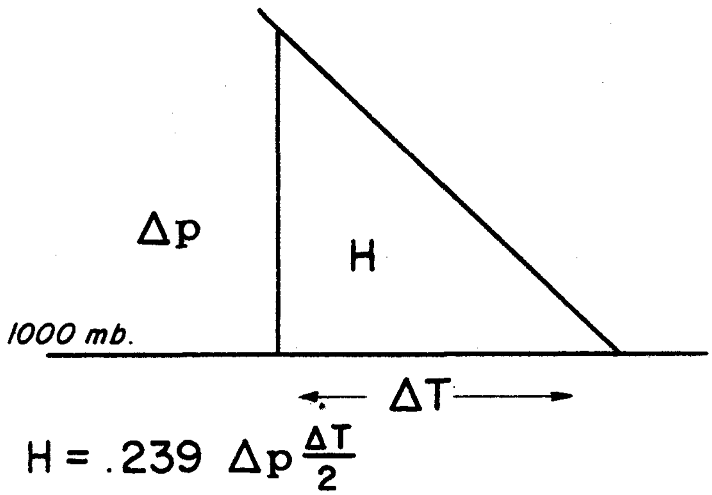

FIGURE 13.—Laying out area corresponding to H on an adiabatic chart.

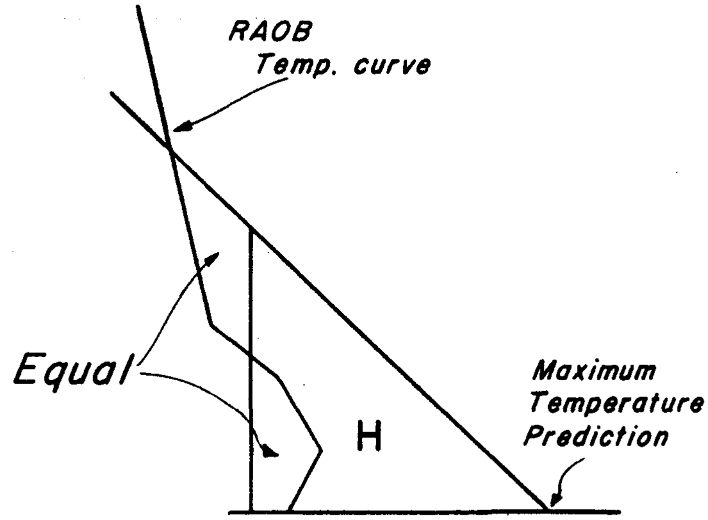

FIGURE 14.—Graphical addition of H area to raob.

Steps in each verification forecast were:

(a) Clear-weather H read off mean curve of figure 12 for particular date.

(b) Kind and amount of cloudiness at Nashville at 1200 CST noted from surface observation form (WBAN 10B). Using the cloudiness from a single observation during the forecast period as representative of the whole period is somewhat comparable in reliability to a cloudiness forecast, when changes during the period would be considered.

(c) Values of H reduced for cloudiness on the following scale:

Overcast	*Percent transmission of sunshine*
Cirrus	84
Cirrocumulus	78
Altocumulus	50
Altostratus	41
Cumulus	25
Stratocumulus	25

These values are given by Haurwitz [5]. He cautions against application to partial sky covers because of reflection from sides of clouds and other effects. Nonetheless for simplicity proportionate allowances were made for fractional sky covers. For example, one-tenth of altocumulus is considered to reduce H 5 percent. Strict logic would require that the insolation and not H be reduced for cloudiness, and also that the net outgoing long-wave radiation should be diminished. However, the simple correction indicated above was considered adequate for present purposes of approximating field forecast conditions.

(d) Triangle laid out as in figure 13 corresponding in area to the adjusted H.

(e) Area added graphically to the bottom of the 2200 CST raob and the maximum temperature read off. Plots on adiabatic charts prepared daily by the National Weather Analysis Center from teletypewriter data were used for this purpose.

(f) Forecast error determined by subtracting the observed maximum temperature from the forecast maximum temperature. The observed maximum temperature for the day, midnight to midnight, was used regardless of the time of day it occurred.

Monthly mean forecast errors are shown in table 9. These are separated into two classes depending on whether or not a front, either warm or cold, passed Nashville during the forecast period. Frontal passages were identified on 3-hour Analysis Center surface charts. If a front was approaching Nashville on one chart but was frontolized on the next chart, it was not counted as a frontal passage.

The forecast errors were separated into four groups: cold season without frontal passage at Nashville during forecast period (March–May and October–November), warm season without frontal passage (June–September), cold-front passage during forecast period (all months), and warm-front passage (all months). The separate frequency distributions are shown in figure 15. The bars are for class intervals of 3° F. centered on the number indicated. The frequency distributions show an encouraging degree of reliability in the forecasts. Forty-two of 98 warm-season forecasts without frontal passages had an error between $-1°$ F. and $+1°$ F. This frequency distribution is quite symmetrical, indicating lack of bias of the warm-season portion of the H curve toward values

TABLE 9.—*Mean monthly errors in daily maximum temperature forecasts (°F.) Nashville, Tenn. Number of forecasts in parenthesis*

Month (1954)	Days without frontal passages	Days with frontal passages
March	4.6 (24)	11.4 (7)
April	3.3 (21)	6.9 (9)
May	3.0 (23)	4.2 (8)
June	2.4 (26)	7.5 (4)
July	1.6 (25)	4.7 (6)
August	3.0 (23)	7.6 (8)
September	2.6 (25)	7.2 (4)
October	2.8 (26)	8.0 (4)
November	3.7 (22)	3.4 (8)

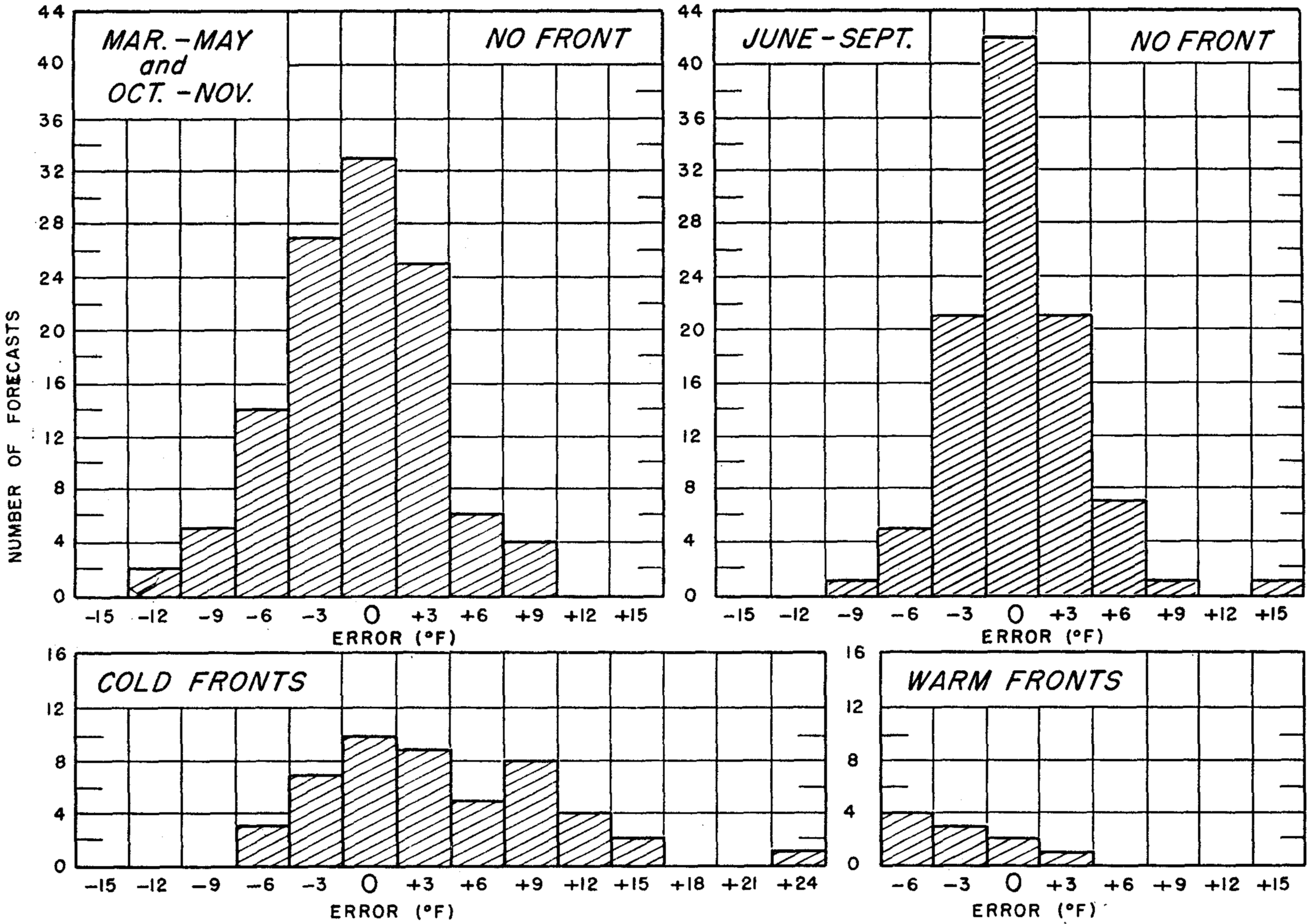

FIGURE 15.—Frequency distributions of errors in Nashville maximum temperature forecasts made using the curve labeled "mean" in lower right panel of figure 12. March through November 1954.

too high or too low. For the cold-season forecasts without frontal passages 33 of 116 forecasts were in the $-1°$ to $+1°$ class interval. That frequency distribution shows a slight skewness toward forecasts that are too low. This could be due to bias in the forecast curve, or possibly to warm advection exceeding cold advection on days of no frontal passages rather than canceling it out. The distributions on days of frontal passage are skewed in the directions one would expect.

Practical application to forecasting.—For a number of years the method described in this paper has been used in conjunction with other methods for maximum temperature forecasts prepared by the Weather Bureau Office at Knoxville, Tenn., for Knoxville and other cities. This is described by Kleinsasser and Younkin [10]. The practice is to predict the clear-weather maximum temperature from the 2200 CST raobs at all raob stations in and around the forecast area and to plot these values on a map. Isopleths of equal values are constructed. The forecaster then makes a subjective allowance for advection and for cloudiness. He also learns to make local allowances for particular stations that are consistently warmer or colder than neighboring stations.

6. NET DAILY HEATING

The net daily local heating of the air at Nashville in clear weather is obtained by adding together the H values for the day, evening, and night periods. Annual curves of these sums are shown in figure 16. Both curves clearly indicate that the net daily heating of the air in clear weather at the latitude of Nashville (36° N.) is sizable, except for a brief period in midwinter. In summer the net daily heating, if restricted to the lower 5,000 feet of the atmosphere, would produce a rise in temperature from 2° to more than 4° C. each day in clear weather. (In a column extending to 5,000 feet a 1° C. mean temperature rise is produced by each 36 langleys added.)

These curves suggest the following conclusions. First, a major factor in warming southward-moving air masses is the greater sunshine at lower latitudes. The heat storage of the ground is minor by comparison. Second, in summer nature invokes certain heat controls which prevent the temperature from rising indefinitely. These operate somewhat as follows: As the surface layers of air become warmer and warmer, the heating is convected to

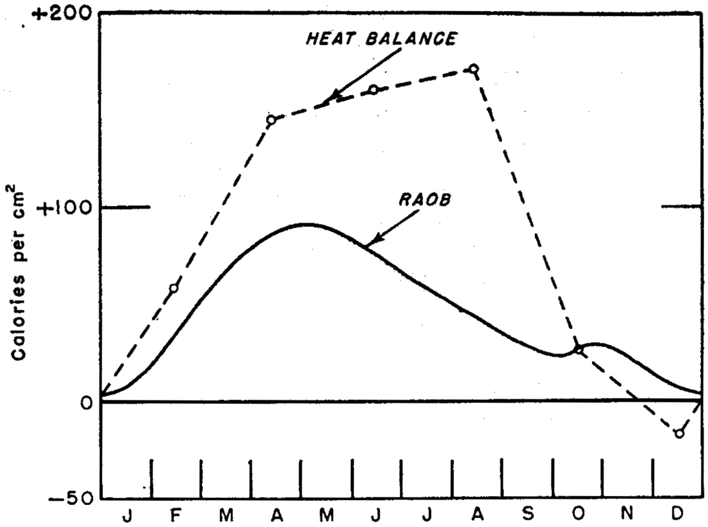

FIGURE 16.—Net daily heating of air in clear weather at Nashville.

higher and higher elevations. In a desert region of little cloudiness the heat must be carried off by the winds. In a more humid climate as the heating extends to higher and higher levels cumulus development automatically becomes greater, intercepting and reflecting some of the sunshine. The cumuli then typically dissipate at night allowing strong nocturnal cooling. The final stage is the development of cumulonimbus clouds. These clouds are an effective thermodynamic vehicle for transporting great quantities of heat from lower to higher layers. The upper layers are warmed by the release of latent heat of condensation while the lower layers are cooled by the evaporation of rain. The role of cumuliform clouds not only as rain producers but as effective summertime heat controls becomes apparent.

7. SUMMARY

The local daily clear-weather heating or cooling is a climatological parameter. This parameter was evaluated on an hourly basis for clear weather at Nashville, Tenn., by an energy-balance technique. Observed temperature changes from raobs agreed well with computed changes on the average for two periods of the day. For the period from 1600 to 2100 CST the mean observed cooling exceeded the computed cooling.

It was shown that the heating parameter is useful in forecasting the daily maximum temperature from the raob of the night before. Mean errors in an objective forecast test, in which advection was neglected but days with front passages were excluded, ranged from 4.6° F. for March to 1.6° F. for July. (An index of cloudiness observed after the other initial conditions was admitted in this test.)

It was shown that at the latitude of Nashville the net daily heating in clear weather is a factor that must be taken into account in explaining summer weather. An appreciable amount of cloudiness is required to maintain a temperature balance in the absence of air mass changes. If subsidence suppresses cloudiness a heat wave is inevitable.

8. SUGGESTIONS FOR FURTHER WORK

Climatological studies to evaluate the local heat balance, similar to the one presented here for Nashville and that by Williams for the Las Vegas-Phoenix area, should be made for other regions. Some of the more recent microclimatological studies, not available at the time this work was begun, should be reviewed in connection with such studies for basic data on ground temperatures, evaporation, etc. The direct absorption of insolation by clear air, which may range up to an equivalent of about 0.7° C. per day [4], and which was neglected in developing the heat-balance diagrams of the present study, should be considered.

There are many other fruitful tasks that could be carried out in organizing, adapting, and bringing to the forecaster's desk available micrometeorological data that have a bearing on the local heat balance. As examples, information is needed on the difference in heat absorption by the ground when dry, wet, frozen, and snow covered. More quantitative work is needed on the effects of clouds on the local heat balance.

The author believes that it would now be feasible to attack the problem of minimum temperature forecasting on an energy-balance basis. This is admittedly more complex than maximum temperatures. The return long-wave radiation from air to ground would have to be taken into account in a more precise fashion than by monthly means. Wind speed would be important but possibly would not prove unduly troublesome. Nights with strong turbulence throughout the night are the exception. The distribution of moisture in the air might possibly have predictive value as to what the night anemometer-level speed will be; the smaller the radiative cooling of the air in comparison with cooling by conduction of heat into the ground, the more stabilizing the situation.

TABLE 10.—*Net cooling of air in clear weather from 1800 to 2115* CST *at Nashville, Tenn.*

Month	Langleys/ hour	Total langleys
February	8.4	27
April	13.1	43
June	14.6	47.5
August	12.8	41.5
October	11.9	39
December	8.0	26

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APPENDIX

The standard raob times were changed on June 1, 1957. A curve for forecasting the maximum temperature from

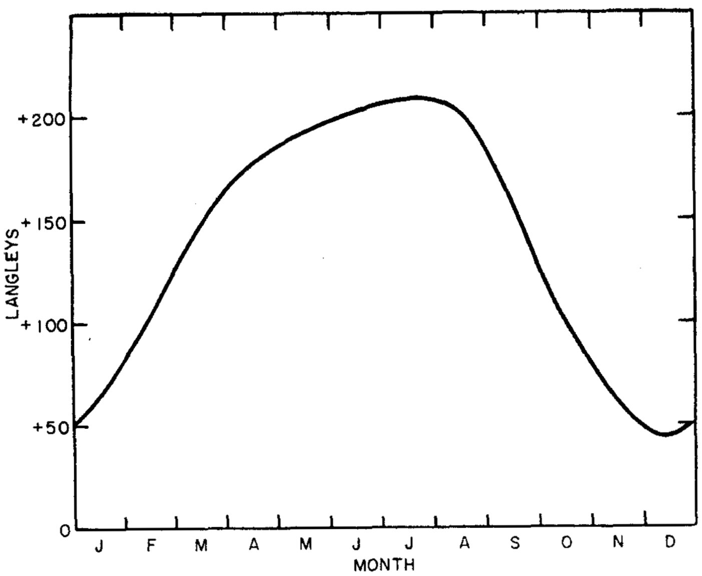

FIGURE 17.—Heating of air in clear weather Nashville. This curve corresponds to the "mean" curve in figure 12 but has been adjusted for use with 1800 CST raob data.

the 1800 CST raob of the evening before is shown in figure 17. This was constructed by measuring the cooling on the air curves of figures 1-6 between 1800 and 2115 CST (1812 to 2127 mean local time) and subtracting this amount of cooling from the mean curve of figure 12. These additional cooling increments are listed in table 10. No verifications have been performed with the curve for the new time.

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